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Plasmonic Antennas Nanocoupler for Telecom Range: Simulation, Fabrication and Near-Field Characterization

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Abstract: We report simulation, fabrication and, for the first time, full amplitude-phase near-field optical characterization in telecom range of the compact and efficient plasmonic nanoantenna based couplers. Near-field data allowed characterizing the subwavelength slot waveguide's propagation losses and effective mode index that correspond well to the simulated ones.

OCIS codes: (180.4243) Near-field microscopy; (250.5403) Plasmonics; (240.6680) Surface plasmons.

Plasmonic waveguides allow for subwavelength mode localization, but with an advantage of tight waveguide integration, the challenge of light coupling into the plasmonic waveguide appears. Various solutions can be applied [1] including gratings, tapered waveguide sections, directional coupling and nanoantennas. Among these approaches plasmonic antennas are the most compact. Nanoantenna as coupler to plasmonic slot waveguide was suggested theoretically [2–5] and then measured experimentally with cross-polarization microscopy [6–7] in telecom and with near-field microscopy in visible [8] and mid-infrared [9] ranges. Nevertheless, near-field characterization of the plasmonic antenna nanocouplers for telecom range has not been demonstrated so far. In this contribution we present, for the first time, amplitude and phase measurements in the telecom range of the propagating plasmons in the slot waveguide excited with a plasmonic antenna [see Fig. 1(a)].

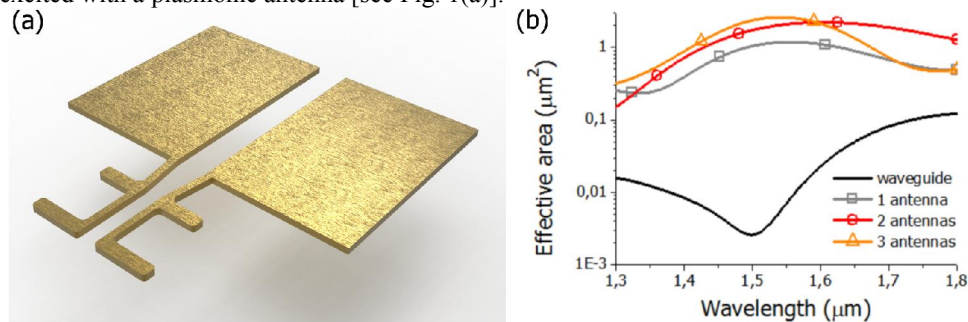


Fig. 1. (a) Plasmonic nanocoupler, consisting of two serial dipole antennas, connected to plasmonic slot waveguide. (b) Effective area of bare waveguide termination (black line), one (grey squares), two (red circles) and three (orange triangles) serially connected antennas.

Antenna coupler demonstrates tremendous coupling efficiency increase of 1000 times compared to the waveguide termination.

Simulation and optimization of the antenna nanocoupler was done in CST Microwave Studio. Effective area (figure-of-merit for the nanocoupler equal to the ratio of coupled power to an incident plane wave's power flux) of a bare waveguide termination, one, two and three serially connected antennas are shown in the Fig. 1(b). At the wavelength 1.5 μm three serially connected antennae demonstrate nearly 1000 times better effective area and thus coupling efficiency compared to the case without antenna coupler.

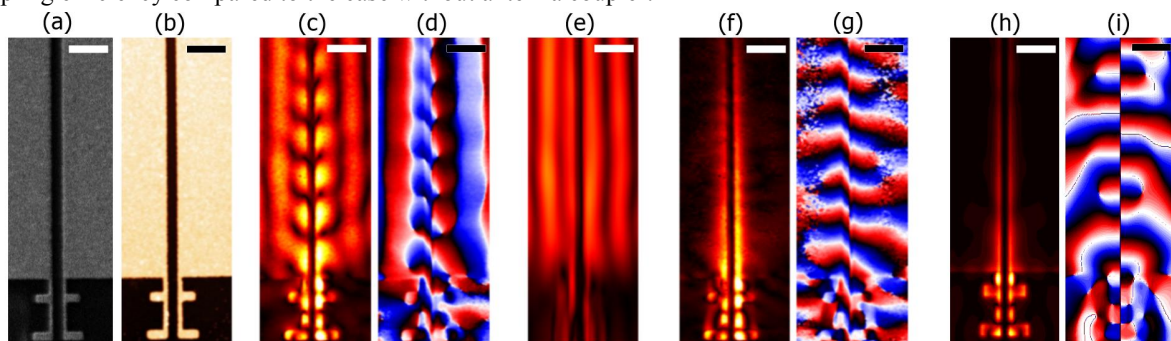


Fig. 2. SEM (a) and AFM (b) topology characterization of the nanocoupler. Pseudocolor s-SNOM images of raw (c) amplitude and (d) phase; (e) amplitude of the background SPPs; (f) amplitude and (g) phase of the slot mode after filtration. The latter correspond well to the numerically modeled amplitude (h) and phase (i). Scale bars are equal to 1 μm .

Fabrication of the sample on double polished 500 μm thick borofloat glass substrate was done with e-beam lithography (ZEP520 resist spinning, 10 nm Al thermal evaporation, e-beam exposure in JEOL JBX-9300FS and development), gold evaporation (Wordentec QCL 800) and lift-off. The sample was then characterized with scanning electron microscope [Fig. 2 (a)] and atomic force microscope [Fig. 2 (b)]. The plasmon excitation was done with the CW tunable laser and measurements were performed with the scattering-type scanning near-field optical microscope in transmission mode (s-SNOM, Neaspec). Measured amplitude [Fig. 2 (c)] and phase [Fig. 2 (d)] of the raw field (component perpendicular to the sample's surface) is formed by the interference pattern between the propagating slot plasmon and surface plasmons excited upon wave's diffraction through the slot. In order to extract the slot plasmon field we filtered out the surface plasmon field [Fig. 2(e)] that is relatively constant along the slot. The filtered experimental field [Fig. 2 (f-g)] is in a good correspondence with the simulation results [Fig. 2 (h-i)].

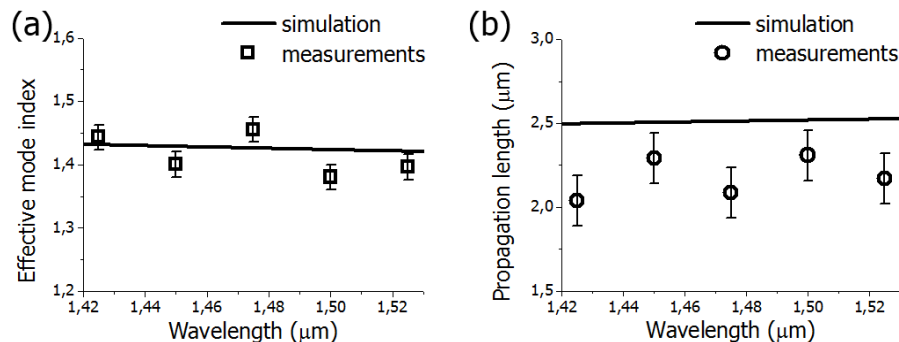


Fig. 3. Simulated (solid lines) and measured (symbols) effective mode index (a) and propagation losses (b) of the plasmonic slot waveguide.

From the measurements of amplitude decay [Fig. 2 (f)] and phase advance [Fig. 2 (g)] at various wavelengths we were able to characterize the effective mode index [Fig. 3 (a)] and propagation length [Fig. 3 (b)] of the plasmonic slot waveguide. The measured effective index corresponds well to the simulated one, while measured propagation length is smaller than the simulated one that can be attributed to the higher losses due to fabricated sample imperfections. We have also confirmed experimentally that the plasmonic antennas are an efficient and compact device for telecom range in-coupling into the subwavelength plasmonic slot waveguide.

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